Robust Logistics Enables a Sustainable Human Presence on Mars

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Buzz Aldrin Space Institute Mars Sustainability Workshop

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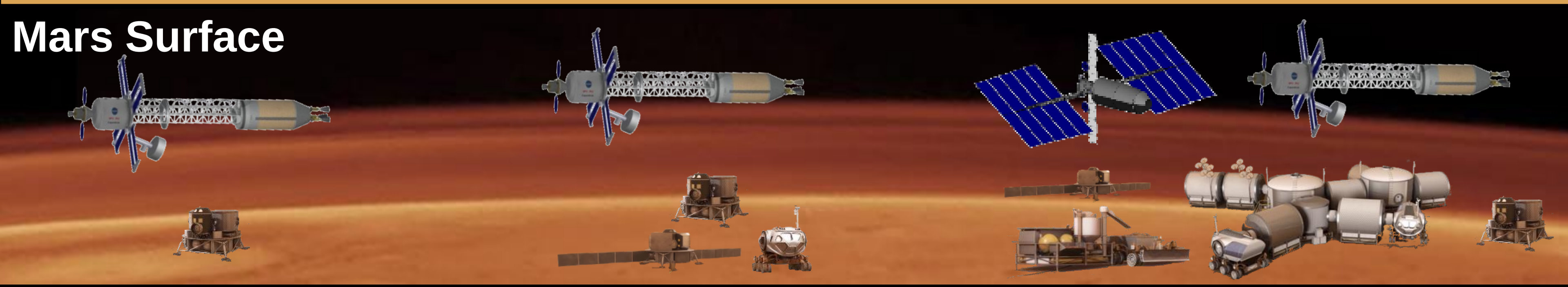
Jet Propulsion Laboratory
California Institute of Technology

Robust Logistics enables Sustained Human Presence

Mars Surface



Sortie|2-3 months → Long Duration|1.5 years → Sustained Presence|*N*+ years

Low Earth Orbit

Sortie|≤2 weeks → Long Duration|3 months → Sustained Presence|17+ years

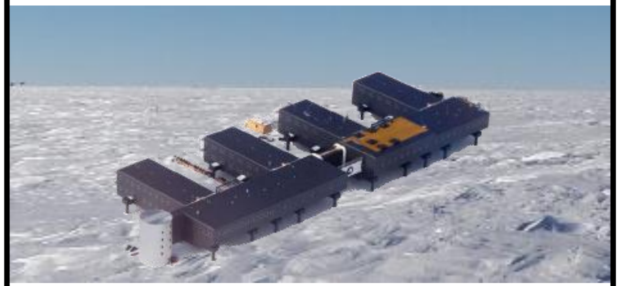
Antarctic South Pole

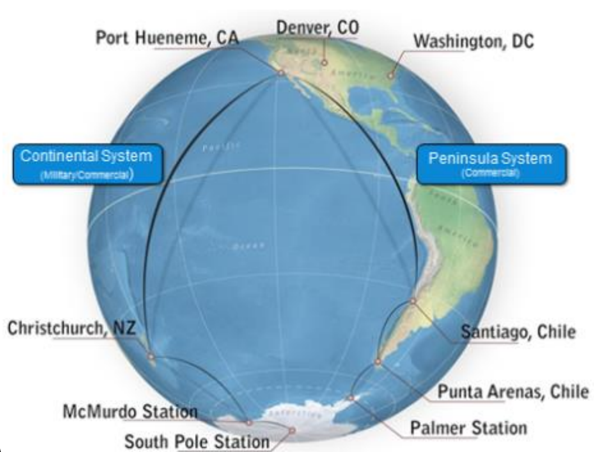
Sortie|4 days → Sustained Presence|61+ years

Transportation **Habitation** **Logistics**

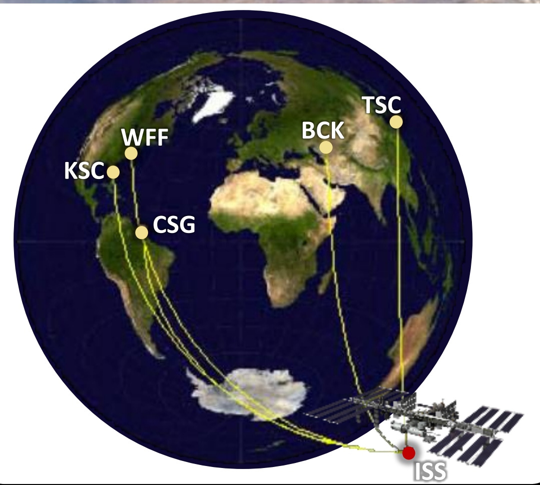
What is the “best” logistics system for Mars?

Antarctic South Pole

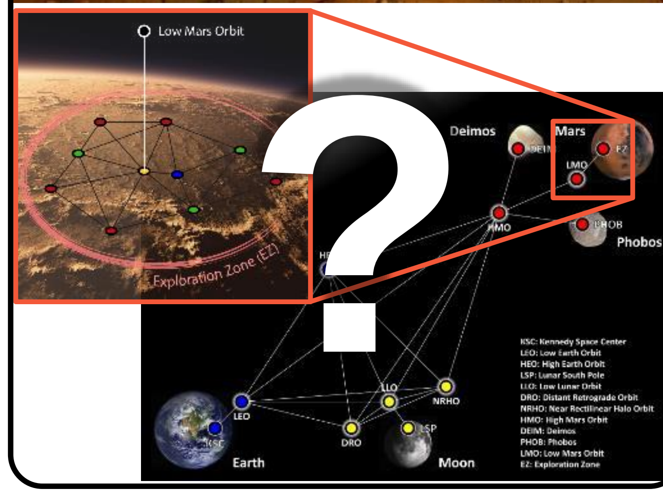




Low Earth Orbit



Mars Surface



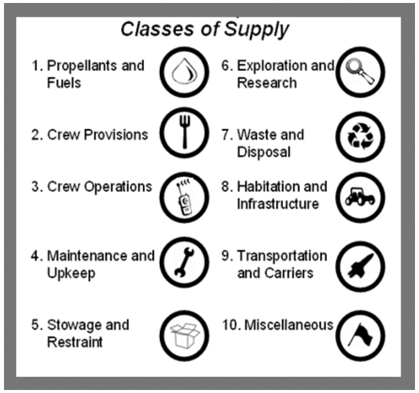
Characteristics of Robust “Sustained Human Presence” Logistics Systems

- Diverse Supply Channels (multi-nodal, multi-modal, multi-partner) with system interoperability
- Generous contingency stores of supplies in multiple accessible locations that are periodically resupplied
- Data-driven spare parts and consumables resupply manifesting
- Safe haven capability to sustain crew until the next rescue/abort opportunity
- Exploitation of in-situ resources and adoption of in-situ manufacturing
- **Economically and politically sustainable**

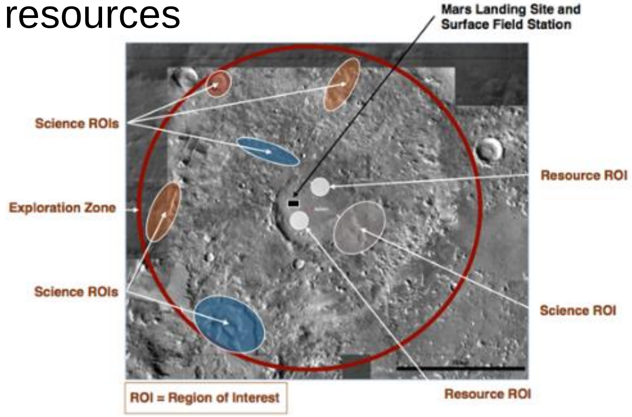
The Challenge: Architecting a Mars Logistics System

Logistics: Ensuring that what is needed, is where it's needed, when it's needed

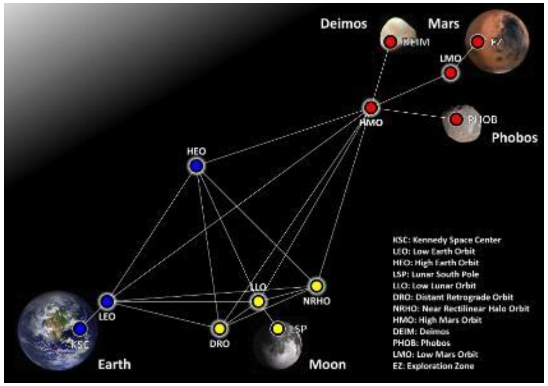
Estimate demands for consumables and spare parts based on the chosen **surface system architecture**



Select **landing site** based on mission objectives, accessibility, landing safety, traversability, surface ops, and locally available resources



Architecting the **in-space and/or surface transportation network** (including depots & caches) to ensure reliable delivery of required goods to the end user



These logistics network decisions are driven by the combination of approaches selected to ensure the availability of each needed resource. The three basic approaches are:

Delivery / Resupply

e.g. Spare parts

Recovery from waste products

e.g. Closed-loop life support

In-Situ Resource Utilization

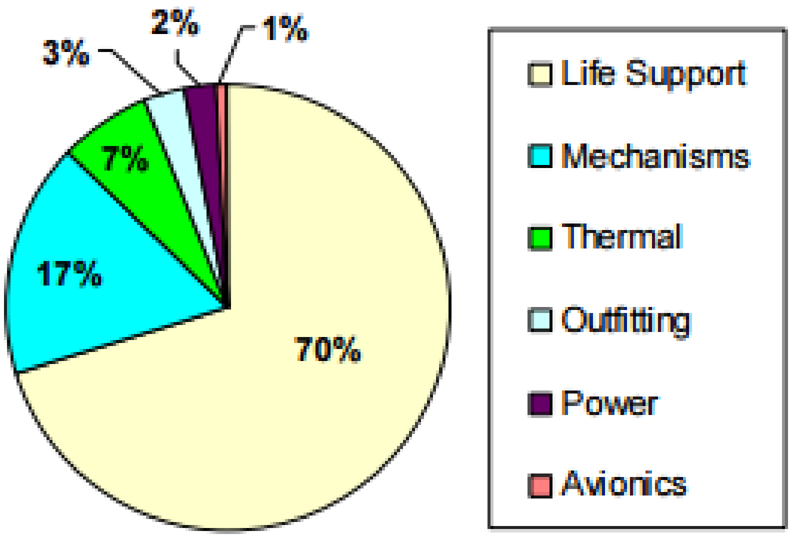
e.g. Solar power

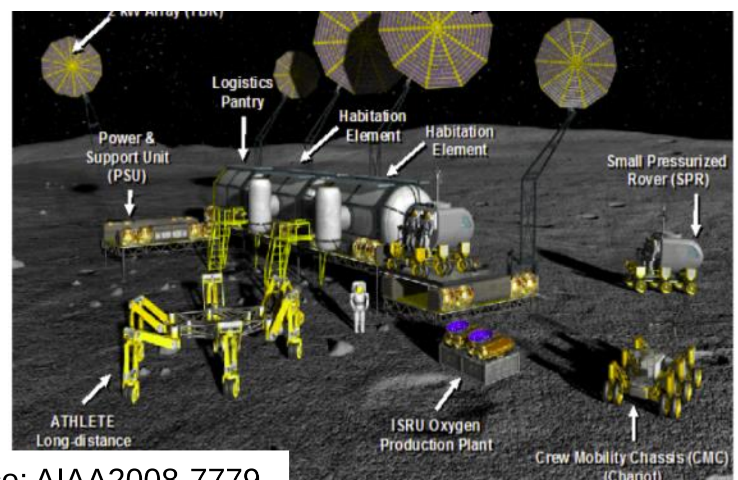
The challenge of architecting a logistics system is: To select a coherent set of strategies that ensures that all resources can be reliably delivered to the crew throughout the life of the program (to within some predefined probabilistic threshold) in a sustainable manner

Key Observations from Previous Research, and a Summary of Current Challenges

Observation: Life Support (ECLS) systems have been found to drive Spare Parts Resupply Requirements

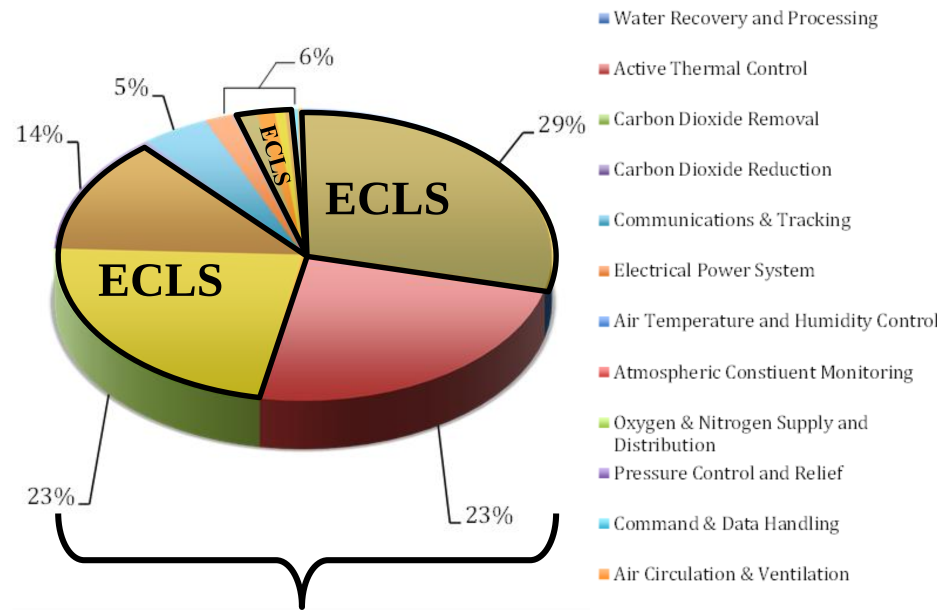
CxP Lunar Base Average Annual Spare Parts Resupply Estimated Demand



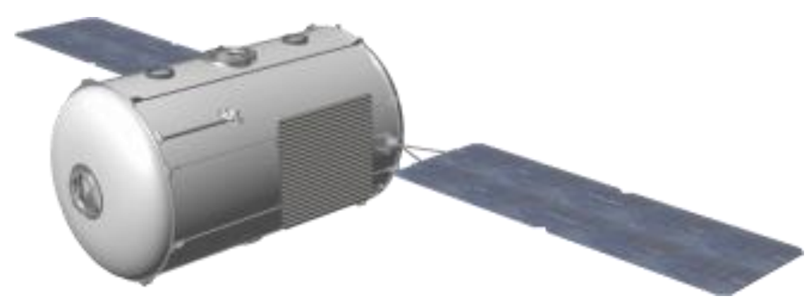


Source: AIAA2008-7779

One year Near-Earth Asteroid mission spare parts requirements



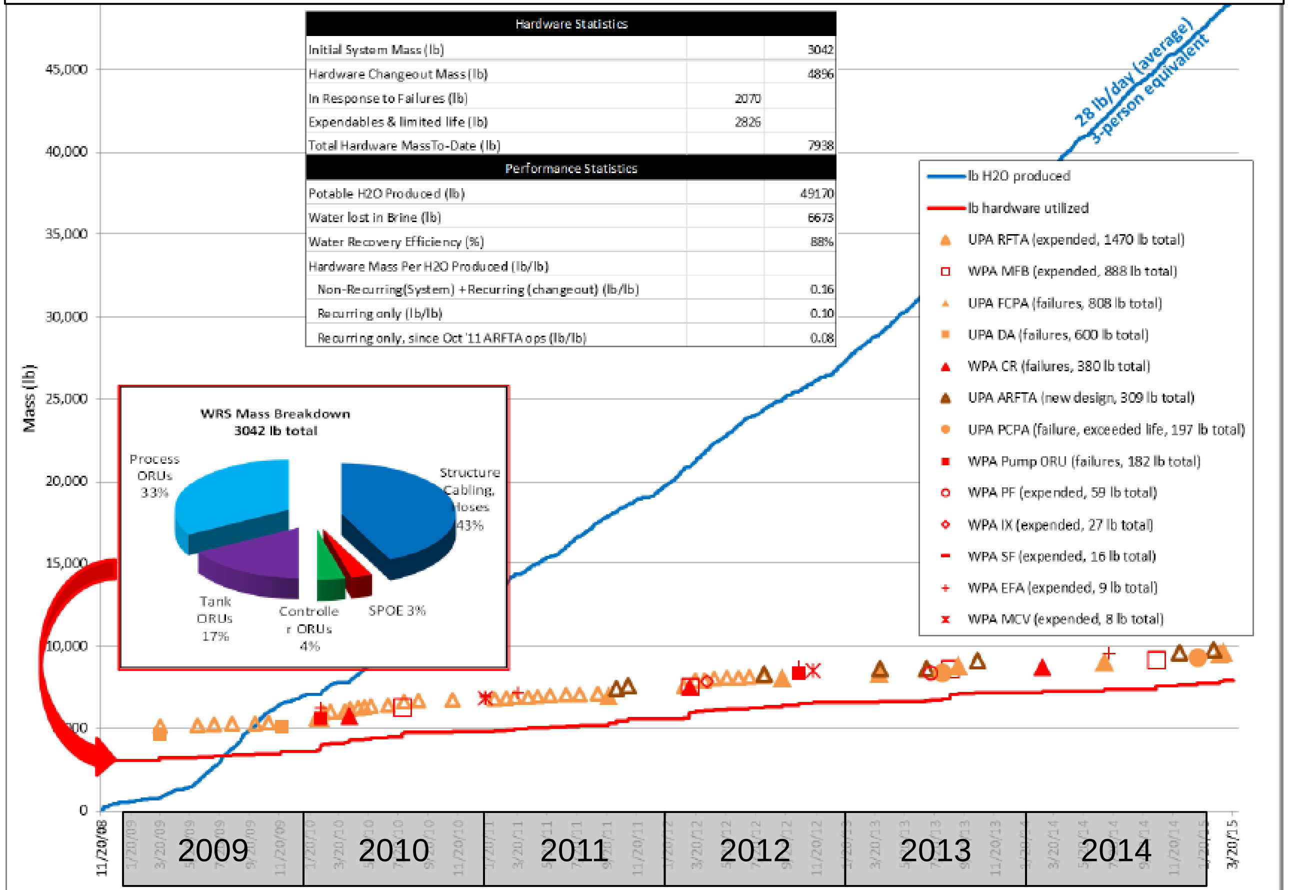
ECLS comprises **~70%** of total spares requirements



Source: AIAA2013-5328

Challenge: Unclear trade between level of recycling, spare parts demand, and crew time

ISS Water Recovery System (WRS) Production Rate and Maintenance Actions: 2009–2014



Bagdigian et al. 2015

Figure 3. Water Recovery System Life Cycle Mass (through March 20, 2015)

Troubleshooting of CDRA during Exp. 26

R&R of UPA DA during Exp. 21

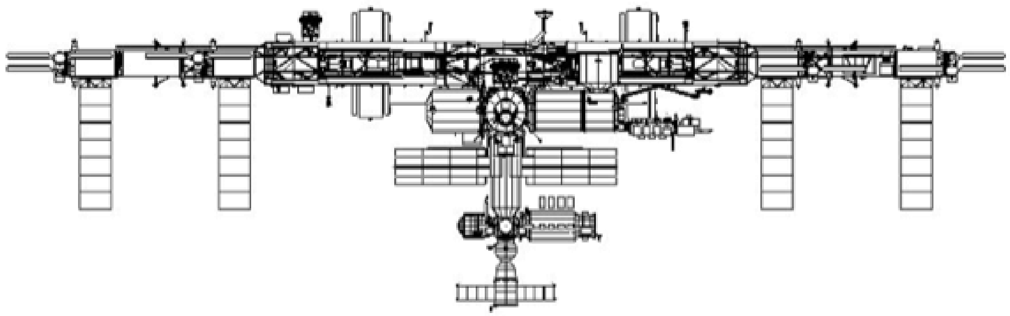
Troubleshooting of WPA during Exp. 23

Water Recovery System saves on water resupply demands but is less reliable than more open loop systems, requiring more spare parts and crew time for maintenance and repair

Predicted ISS Logistics Requirements 2012-2020

Total Approx. Spares Mass Currently On-Orbit = **13,170kg**

Mass estimates are for mass of spare item only - do not including any packaging or carrier mass



Predicted Annual Average Upmass 2012-2020

Corrective Maintenance = *1,260 kg*

Preventive Maint. / Consumables = *1,930 kg*

Total = ***3,190kg***

*Expected Average Annual Failures** =

450kg

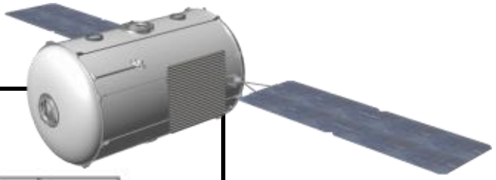
Total Approx. Spares Mass Currently Stored On Ground = ***17,990kg***

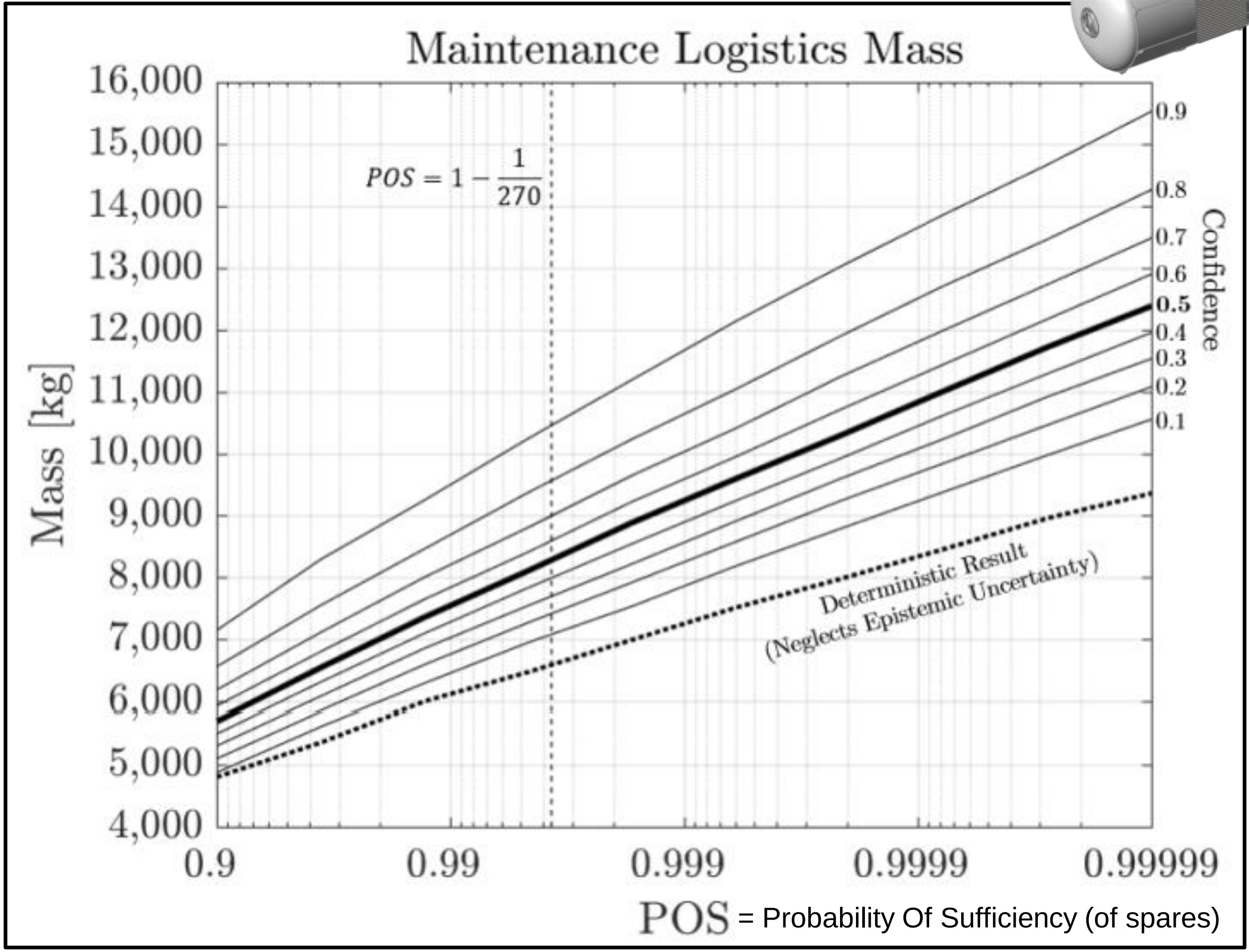
Source: AIAA 2011-7231

**- based on predicted MTBFs*

Challenge: Uncertainty in System Reliability Drives Large Spare Parts Demand (2/2)

Case study: 4 crew, 1100 day Deep Space Habitat with ISS-based ECLS

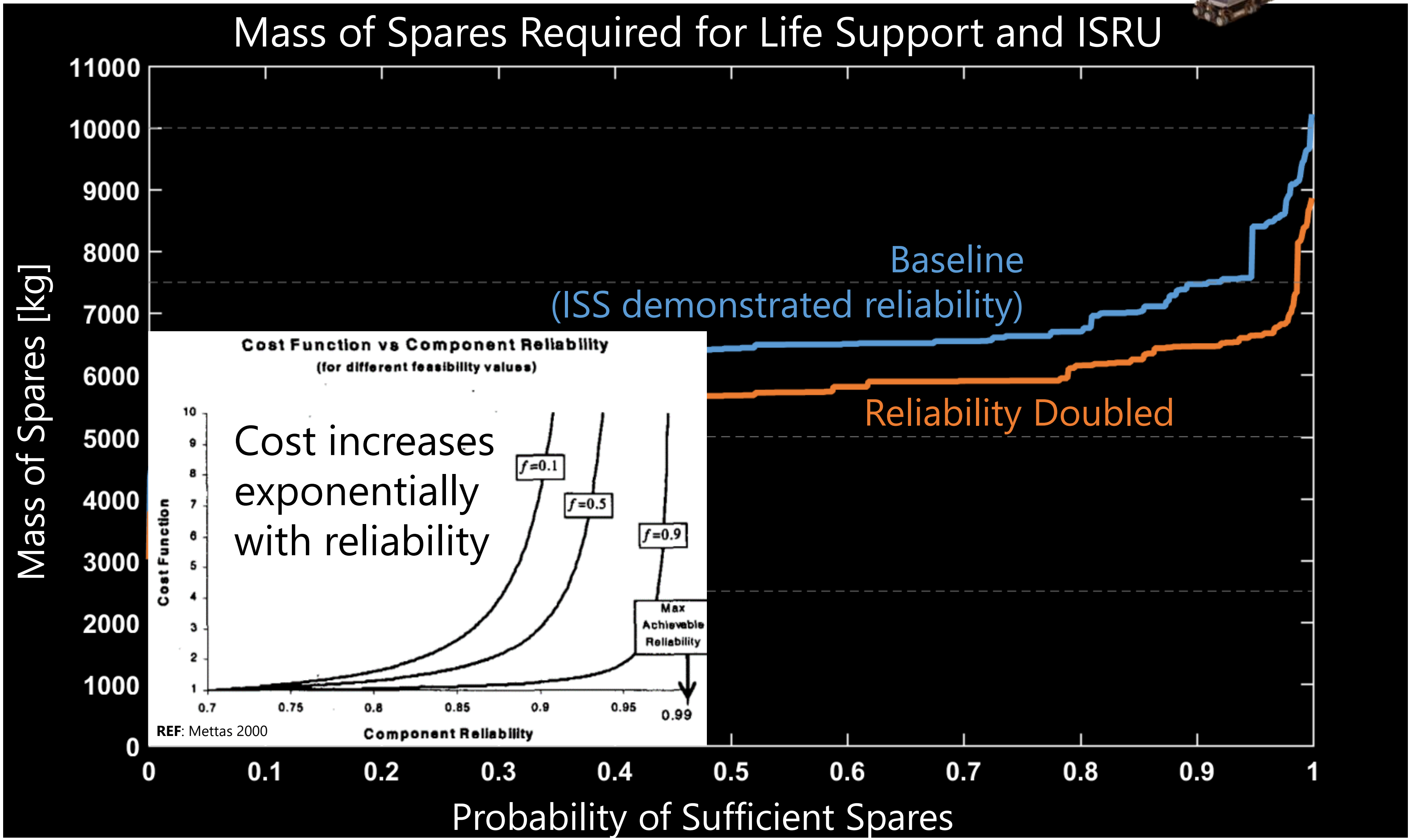




Source: Owens et al., ICES2017-109

Challenge: Increasing system reliability may not significantly reduce logistics demand

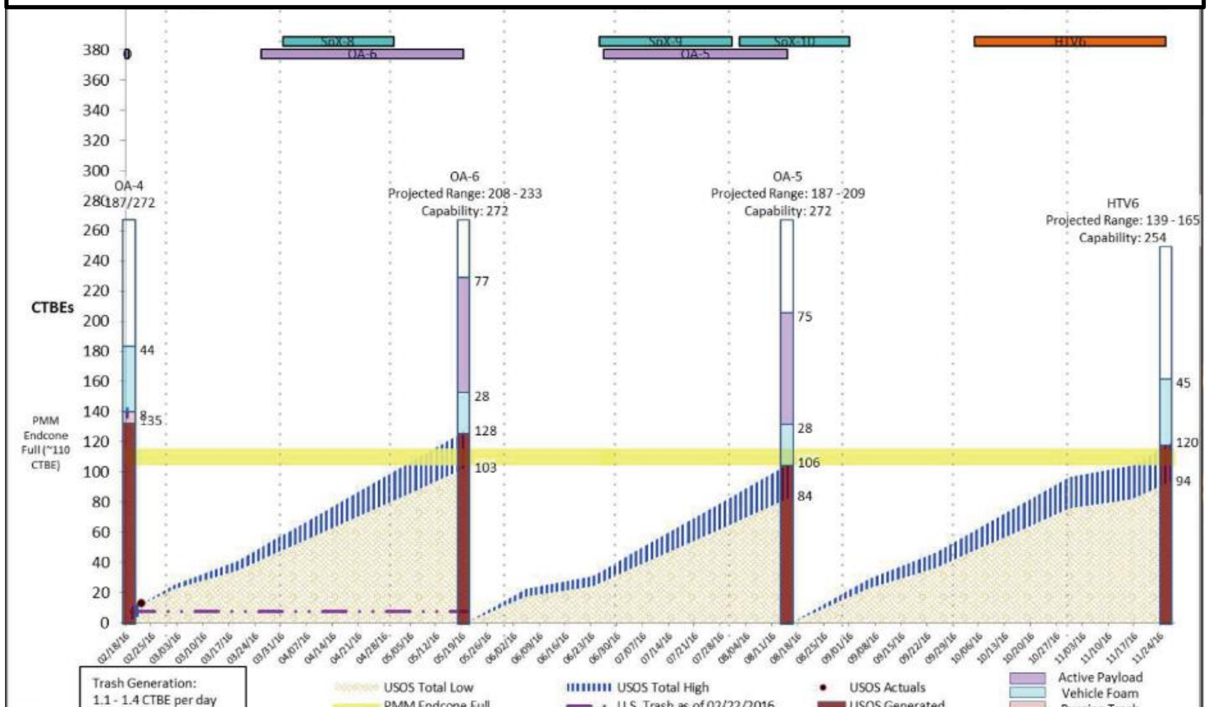
Example result: 4 crew, 26 months, ISS-derived ECLS
Spares demand driven by scheduled, rather than random repair



Challenge: Mars surface waste management

- The South Pole Station and ISS waste management strategies both rely on departing logistics vehicles to dispose of waste
- Further research is needed on what an effective **Mars surface waste management strategy** might look like, given the constraints of planetary protection and the prohibitive costs involved in returning mass from the surface

ISS: predicted onboard trash from Feb 2016 to Oct 2016



Source: J. Keaton, NASA HQ

Additional Challenges and Potential Next Steps

- **Logistics demands** are driven by the system architecture on the surface of Mars, which needs further characterization. However, logistics demands should also be factored into the selection of the **surface system architecture**. Therefore:
  - **Reliability and spare parts demands of all surface system options**, such as: rovers, ISRU, civil engineering, power and thermal, ECLS, EVA, and waste management systems, etc. need to be estimated
  - Given the inherent uncertainty in these estimates, the most comprehensive analyses that can likely be done involve: **comparative analyses of different architectures incorporating different technology options** to investigate their total logistics demands. This will reveal which technology options are preferred and under what conditions
- What spare parts demands can be effectively reduced with **in-situ manufacturing** (including the impact of providing feedstock and logistics of the manufacturing systems)?
- Analyses have yet to be done on where **safe havens** might be placed in the Martian system, what their functions might be, and the extent to which they might reduce mission risk
  - The location of the selected landing site may constrain this
- Comparative, first-order **cost analyses** should be performed as a means to evaluating the sustainability of competing system and logistics architectures. This should include an analysis of potential commercial and international contributions.
- The selection of a **landing site** is primarily driven by the availability of water
  - NASA is funding a series of studies aimed at mapping the distribution of water on Mars
  - Preliminary results are expected in late 2018/early 2019
  - In the meantime, it is recommended that representative landing sites be developed/selected (from those proposed in the 2015 NASA Exploration Zones Workshop) and used as the basis of study

Thank you!